

A photograph of a mountain peak, likely Longs Peak, with a weather station and two people. The weather station is a tall pole with several sensors at the top, secured by ropes. Two people are standing on the rocky summit. The background shows a vast mountain range under a cloudy sky. The text is overlaid on the image.

***WIND AND MOUNTAIN  
CLIMATOLOGY IN  
SEVERE ENVIRONMENTS:***

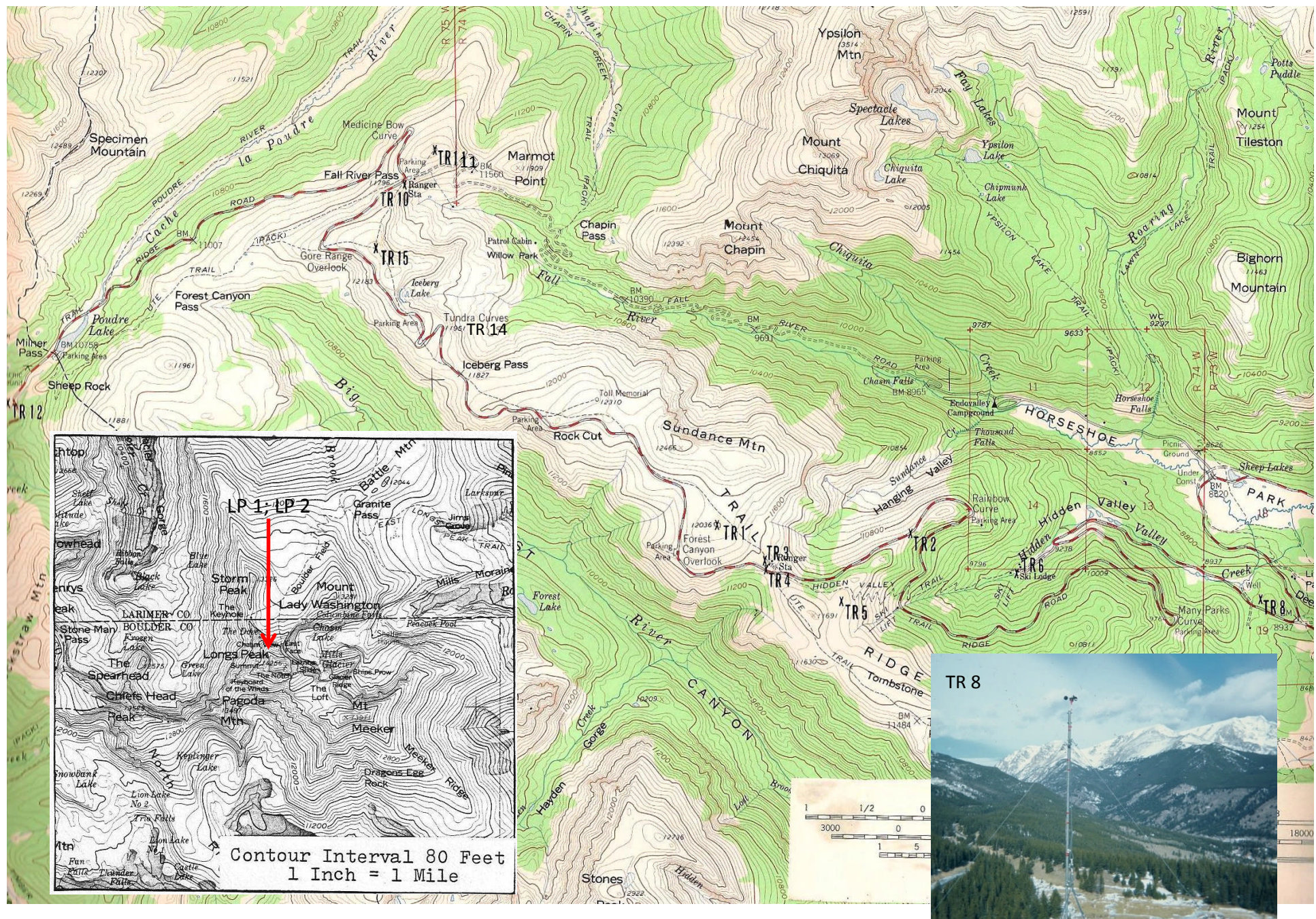
**SUPERHURRICANE WINDS AND  
EXTREME GUST FACTORS  
AT LONGS PEAK AND  
ROCKY MOUNTAIN NATIONAL PARK**

**D. E. GLIDDEN**

***OCCASIONAL PAPER, JUNE 2016***

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WIND RESEARCH SITES IN ROCKY MOUNTAIN NATIONAL PARK (EXCLUDES TR 7, PARK HQ)



## INTRODUCTION

WIND STUDIES IN ROCKY MOUNTAIN NATIONAL PARK DURING 1973-74 AND 1980-81 PROVIDE A UNIQUE SOURCE OF DETAILED DATA FOR THE PARK. THE FOLLOWING GRAPHS AND TABLES OFFER SELECTED SUMMARIES OF FIELD DATA, IN PART TAKEN FROM THE PUBLISHED STUDIES. SOME OF THIS DATA WAS COLLECTED BUT NEVER PUBLISHED IN THE ORIGINAL FIELD WORK. FOR DETAILED DISCUSSIONS AND EXPLANATIONS OF THIS DATA, PLEASE CONSULT THE ORIGINAL PUBLICATIONS REFERENCED BELOW:

**Glidden, D. E., 1974, *Analysis of Alpine and Subalpine Wind Conditions in Winter, RMNP*, National Park Service; 1982, *Winter Wind Studies in Rocky Mountain National Park*; 1981, *Summer Wind Studies Near the Alpine Visitors' Center, Rocky Mountain National Park*. Copyright 1981, 1982 by the Rocky Mountain Nature Association; 2011, *Significant Disturbance Patterns of 12-13 November 2011 Wind Storm in Rocky Mountain National Park*, [irma.nps.gov](http://irma.nps.gov)**

### LONGS PEAK: WINTER 1980-81

#### Special Environmental Problems

The summit of Longs Peak, at 14,256 ft (4,345 m), presents a formidable challenge, particularly to human researchers, but also to the operation, regular servicing, and durability of even specially-designed wind instruments. Research during the winter of 1980-81 clearly demonstrated the level of human energy and logistical support which are required to secure even 74 days of data.

A specially-constructed, low profile shelter was transported to the summit in September of 1980, and afforded protection for instruments and Park Rangers while servicing the station. Since it was known that winds may induce a severe vibration on the summit, producing both an audible roar and a "noise" which has been detected through sensitive acoustic instruments as far away as Boulder, it was necessary to surround the shelter with large blocks of rock.

Hard rime ice was cleared from the 3.6 m instrument tower on some winter visits. Sensor height and location, now believed to represent a "wind shadow" on the western summit expanse, may have minimized some windspeeds under certain wind direction regimes, although this is not clear. On the other hand, the effects of rime on unheated wind sensors are quite well known. Data on rime frequency on Longs Peak are not available; however, since the summit is often in a cap cloud when Trail Ridge is clear, it is thought to be high.

Information for even 74 days offers a glimpse of what must be considered an extraordinary environment: frequent wind gusts approaching twice hurricane-force, several over 170 mph (76 m/s), and at least one registering 201 mph (89.8 m/s)!

	<u>WINTER<sup>1</sup></u>		<u>SUMMER<sup>2</sup></u>	
	<u>LONGS</u>	<u>PEAK</u>	<u>AVC</u>	
	<u>mph</u>	<u>m/s</u>	<u>mph</u>	<u>m/s</u>
Peak Gust <sup>3</sup>	201	89.8	79	35
Average Daily Maximum	64.9	29.0	47.8	21.4
Maximum One-Hour Average <sup>4</sup>	101	45.1	49	22
Maximum Daily Average	50.2	22.4	34	15.2
Period Average <sup>5</sup>	16.7	7.4	20.2	9.0
No. Days Peak Gust $\geq 74$ mph	24		4	
Maximum Hourly Gust Factor <sup>6</sup>	5.20		4.28	
Average Maximum Hourly GF	3.20		2.20	
Average Hourly GF	2.00		1.58	
Average Minimum Hourly GF	1.30		1.21	
Minimum Hourly GF	1.00		1.00	
Days With Data <sup>7</sup>	74		87	
% Days With Data	27.3		95	

1. Winter - August 30, 1980-May 31, 1981  
 2. Summer - June 2 - August 28, 1980  
 3. The maximum windspeed measured.  
 4. The highest average hourly windspeed.  
 5. The average windspeed for all days with data. Exposure and sensor icing problems may have substantially reduced the Longs Peak average.  
 6. Gust Factors are based on 24 hourly values for each day with data.  
 7. Days with data vary with particular averages.

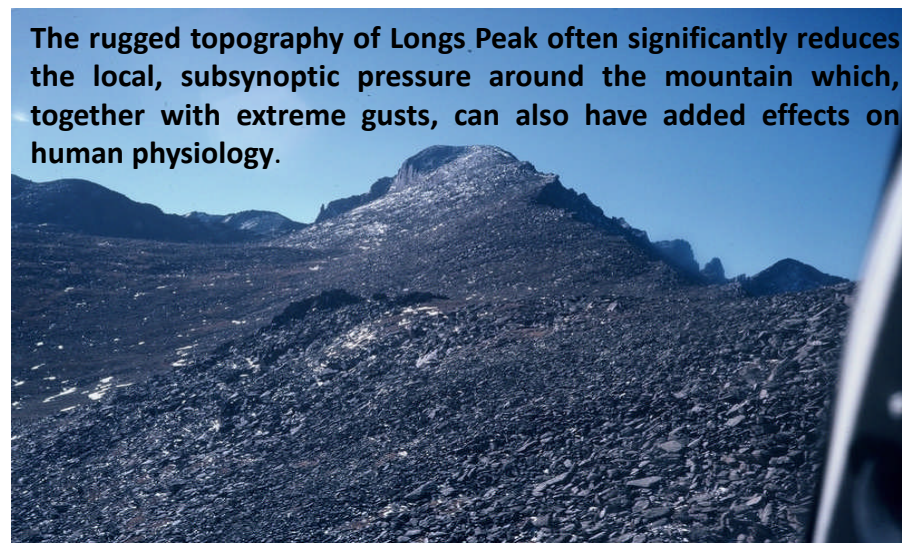
**WIND AND GUST FACTOR REGIMES FOR LONGS PEAK (LP 1 AND LP 2) AND ALPINE VISITORS' CENTER (AVC), RMNP**



<u>Hourly Peak Gust</u>	<u>Total Hours of Occurrence</u>	<u>Total Hours of Occurrence</u>	<u>Frequency Distribution</u>	
<u>MPH</u>	<u>Number</u>	<u>%</u>	<u>MPH</u>	<u>%</u>
0-9	141	9.27	$\approx 0$	100.00
10-19	217	14.27	$\approx 10$	90.73
20-29	376	24.72	$\approx 20$	76.46
30-39	290	19.07	$\approx 30$	51.74
40-49	195	12.82	$\approx 40$	32.67
50-59	143	9.40	$\approx 50$	19.85
60-69	61	4.01	$\approx 60$	10.45
70-79	37	2.43	$\approx 70$	6.44
80-89	21	1.38	$\approx 80$	4.01
90-99	11	0.723	$\approx 90$	2.63
100-109	12	0.789	$\approx 100$	1.91
110-119	3	0.197	$\approx 110$	1.12
120-129	5	0.329	$\approx 120$	0.920
130-139	3	0.197	$\approx 130$	0.591
140-149	3	0.197	$\approx 140$	0.394
$\approx 150$	3	0.197	$\approx 150$	0.197

Total Hours = 1,521  
 Total Possible Hours = 6,600 (August 30, 1980-May 31, 1981)  
 Percent of Hours With Data = 23%

**THE HOURLY PEAK GUST FREQUENCY REGIME FOR LONGS PEAK**



The rugged topography of Longs Peak often significantly reduces the local, subsynoptic pressure around the mountain which, together with extreme gusts, can also have added effects on human physiology.



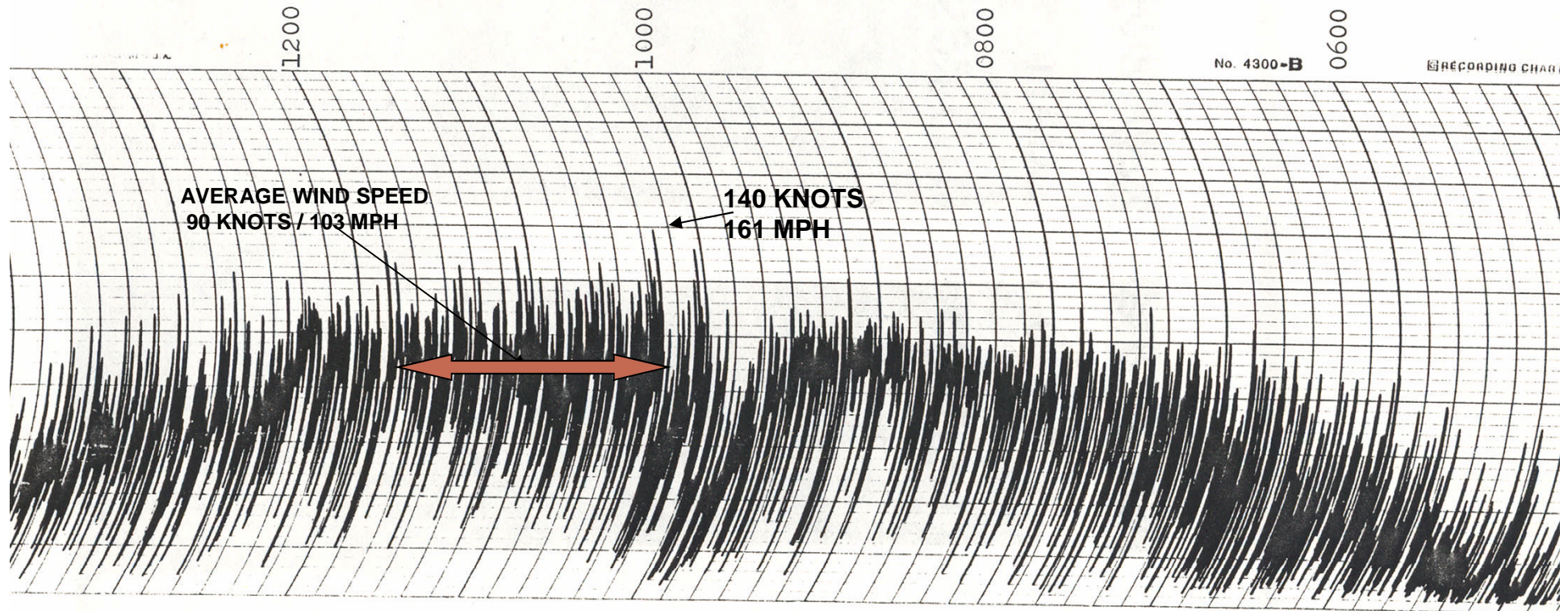
## **LONGS PEAK SUMMIT ON JANUARY 24, 1981**

**MAXIMUM RECORDED PEAK GUST = 161 MPH**

**MAXIMUM 5-MINUTE AVERAGE = 114 MPH**

**MAXIMUM 1-HOUR AVERAGE = 101 MPH**

**MAXIMUM PEAK GUST RECORDED FOR WINTER 1980-81= 201 MPH**

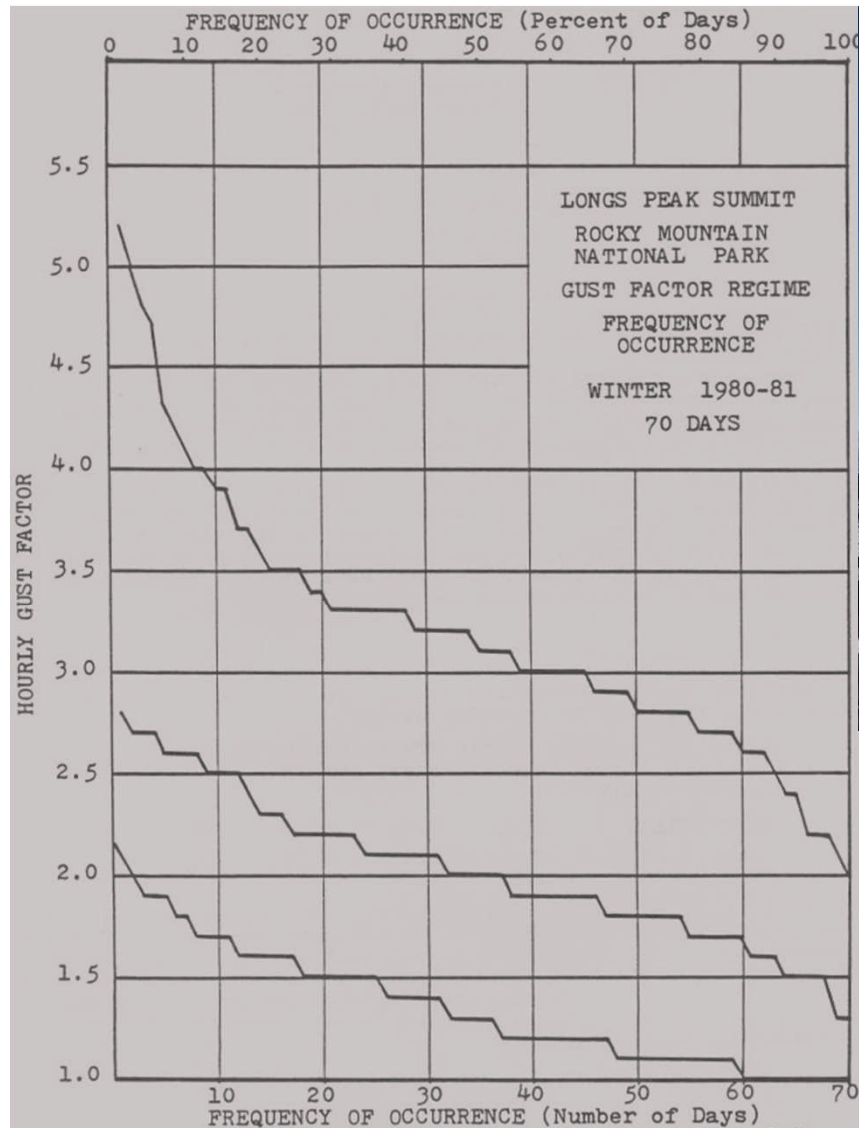


After D. E. Glidden, *Winter Wind Studies in Rocky Mountain National Park*, 1982

FIG. 14

Anemograph of severe winter storm on Longs Peak,  
January 24, 1981. Scale: 0-200 knots (uncorrected).  
Note the extreme range of turbulence.





The number of days or percent of days the daily maximum, mean, and minimum gust factors were equal to or greater than a particular value.

#### 1. Gust Factor Regimes

The relationship of gust factors (GFs) and average windspeeds were discussed with some detail in the summer study (Glidden, 1981, pp. 26-35). Gust factors are determined from the ratio of the peak gust to the average windspeed for some specified period of time. For example, the hourly GF refers to the ratio of the peak gust/average hourly windspeed; the 5-minute GF is the ratio of the peak gust/average 5-minute windspeed.

Detailed hourly GFs for Longs Peak (70 days), TR 3 (29 days), and TR 10 (87 days) are listed in Table 14.

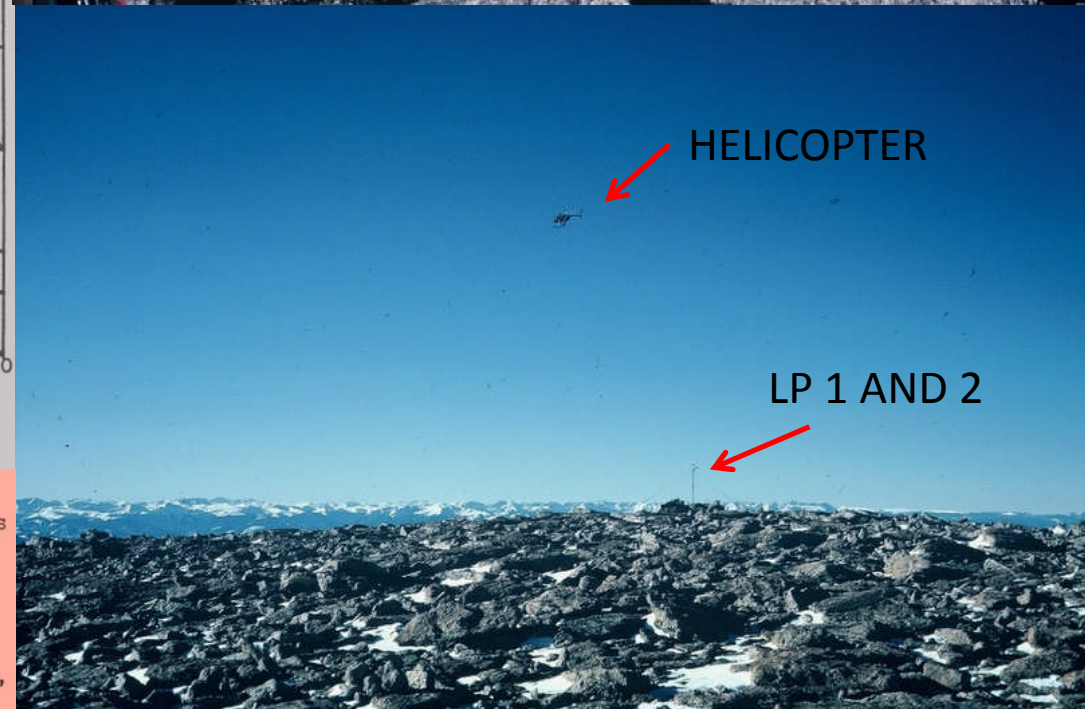




Table 16. Five-minute GFs for daily maximum 5-minute average windspeeds, Longs Peak, RMNP.

Maximum	6.17
Mean	1.79
Minimum	1.10
Days With Data	61

Table 17. Average hourly GFs at 6-hour intervals, Longs Peak (70 days) and TR 3 (29 days) RMNP.

Hour Ending	0100	0700	1300	1900
Longs Peak	2.16	2.23	2.08	1.96
TR 3	1.58	1.84	1.62	1.51

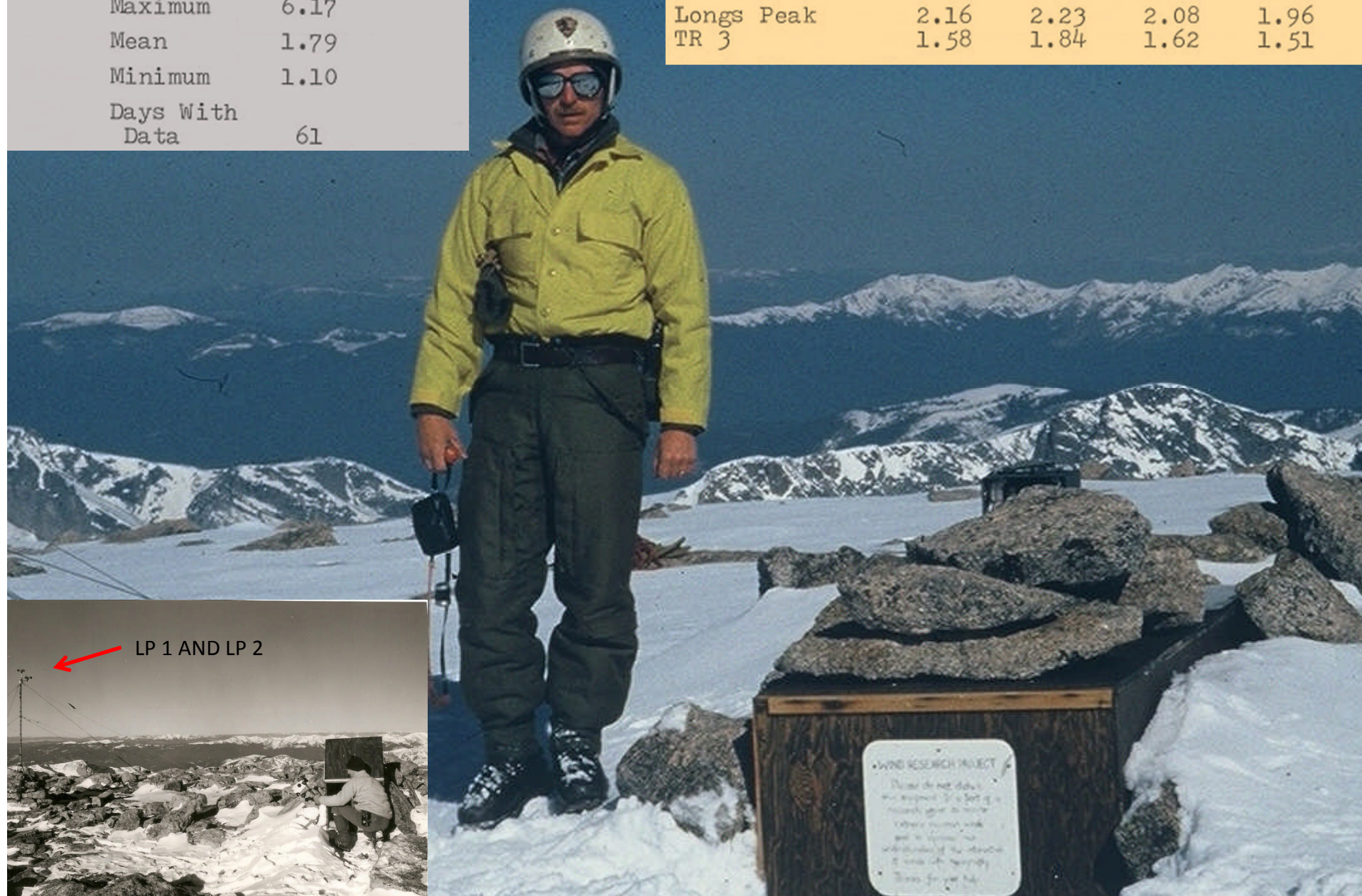




Table 14. The hourly GF regimes for Longs Peak, TR 3, and TR 10, RMNP.

	<u>Longs Peak</u> (Winter)	<u>TR 3</u> (3/74)	<u>TR 10</u> (Summer)
Maximum	5.20	3.50	4.28
Average			
Maximum	3.20	2.53	2.20
Average	2.00	1.61	1.58
Average			
Minimum	1.30	1.27	1.21
Minimum	1.00	1.00	1.00
Days With Data	70	29	87

Table 15. The percent of days with GFs  $\geq$  particular values, Longs Peak and TR 10, RMNP.

	<u>Longs Peak</u> (Winter)	<u>TR 10</u> (Summer)
Mean Daily GFs		
$\geq 1.5$	97	80
$\geq 2.0$	53	1
Maximum Daily GFs		
$\geq 3.0$	64	10
$\geq 4.0$	13	1
Days With Data (Number)	70	87

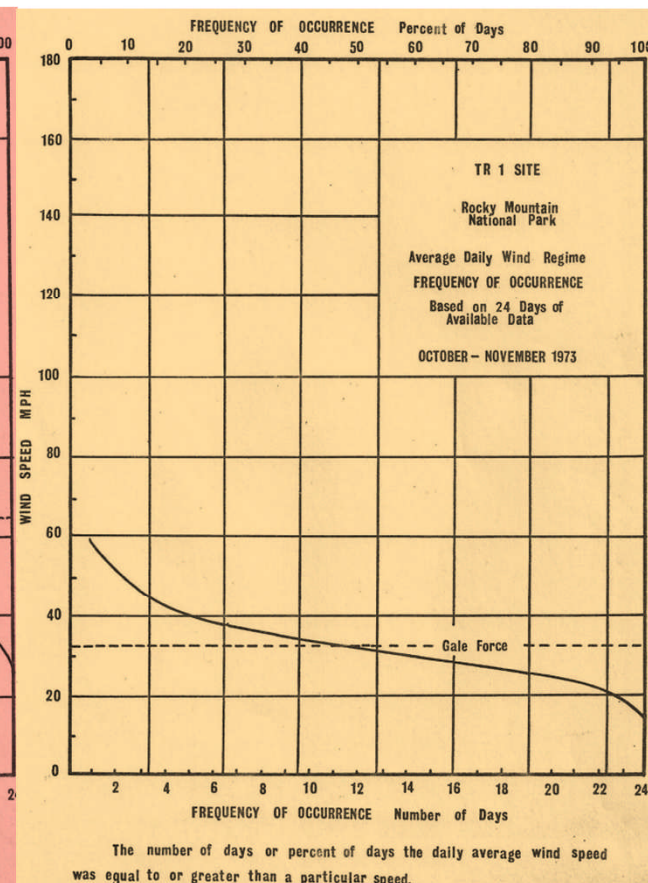
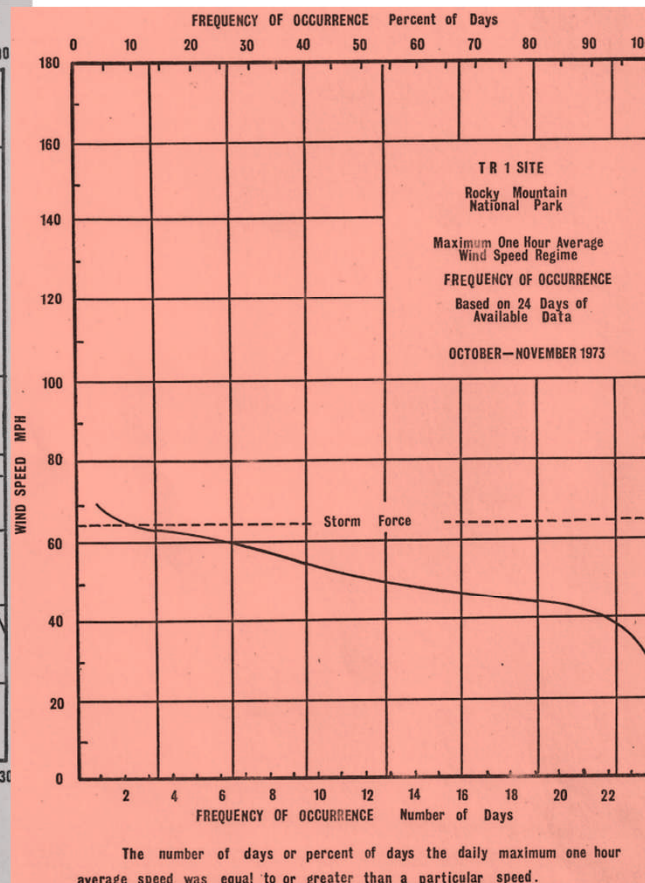
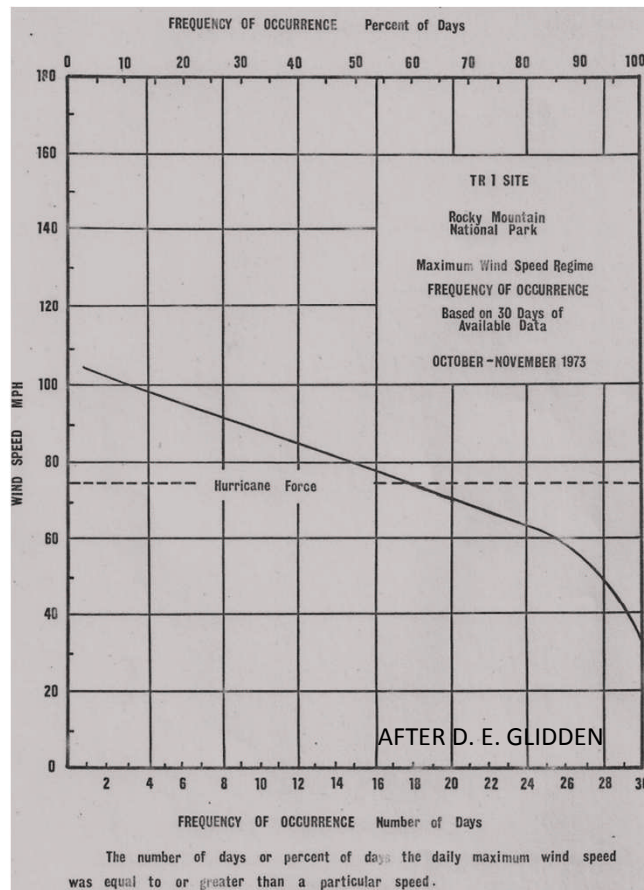
THE STRONG INFLUENCE AND DESSICATION EFFECTS OF WIND ABOVE TREE LINE. RAINBOW CURVE AND TRAIL RIDGE ROAD ARE IN THE DISTANCE. "KNIFE EDGE," WHERE KATHERINE BELL AND EMILY FOSE OFTEN CRAWLED IN SUPERHURRICANE WINDS DURING WINTER 1971, IS JUST OUT OF SITE.



LONGS PEAK INSTRUMENT SHELTER, 1980-81







RANGER STEVE HICKMAN AT TR 1 SITE ABOVE FOREST CANYON OVERLOOK, DEC. 1973. LONGS PEAK IS IN A CAP CLOUD DIRECTLY BEHIND THE MAST, SOME 14 AIR MILES AWAY.

Table 7. The frequency of occurrence of daily wind maxima  $\approx 74$  mph (33 m/s) and  $\approx 100$  mph (45 m/s) at TR 3, October 1973-May 1974.

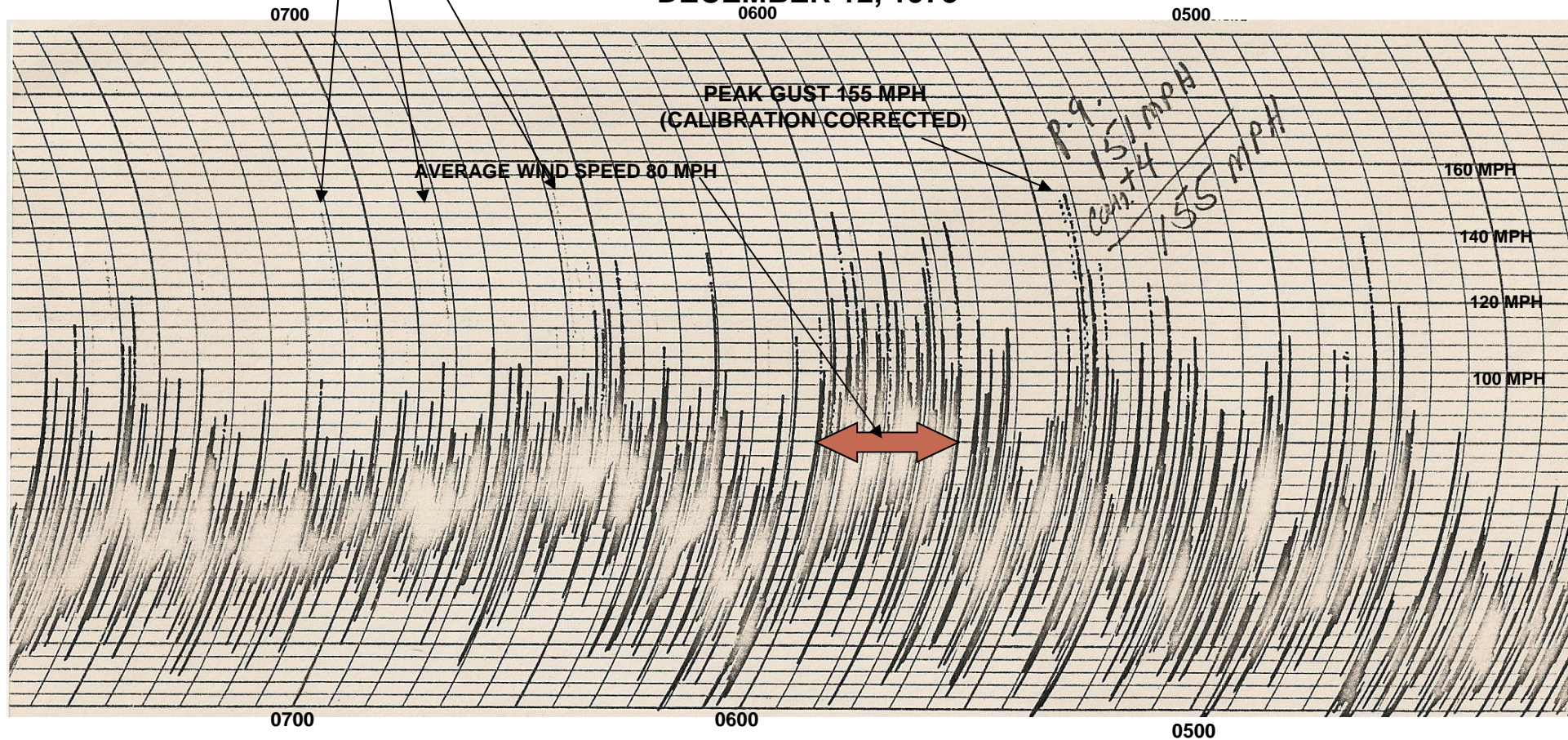
	O-N <sup>1</sup>	J <sup>2</sup>	F	M	A	M	PERIOD
No. Days $\approx 74$ mph	18	15	11	17	5	9	75
% Days $\approx 74$ mph	60	62	39	61	20	32	46
No. Days $\approx 100$ mph	3	4	4	4	1	3	19
% Days $\approx 100$ mph	10	17	14	14	4	11	12
Days With Data	24	24	28	28	25	28	157

1. Data from TR 1
2. January daily peak gust data for 24 days



NOTE NUMEROUS FAINT AND INTERMITTENT INK TRACES > 140 MPH

**TR 1 SITE, ROCKY MOUNTAIN NATIONAL PARK  
DECEMBER 12, 1973**



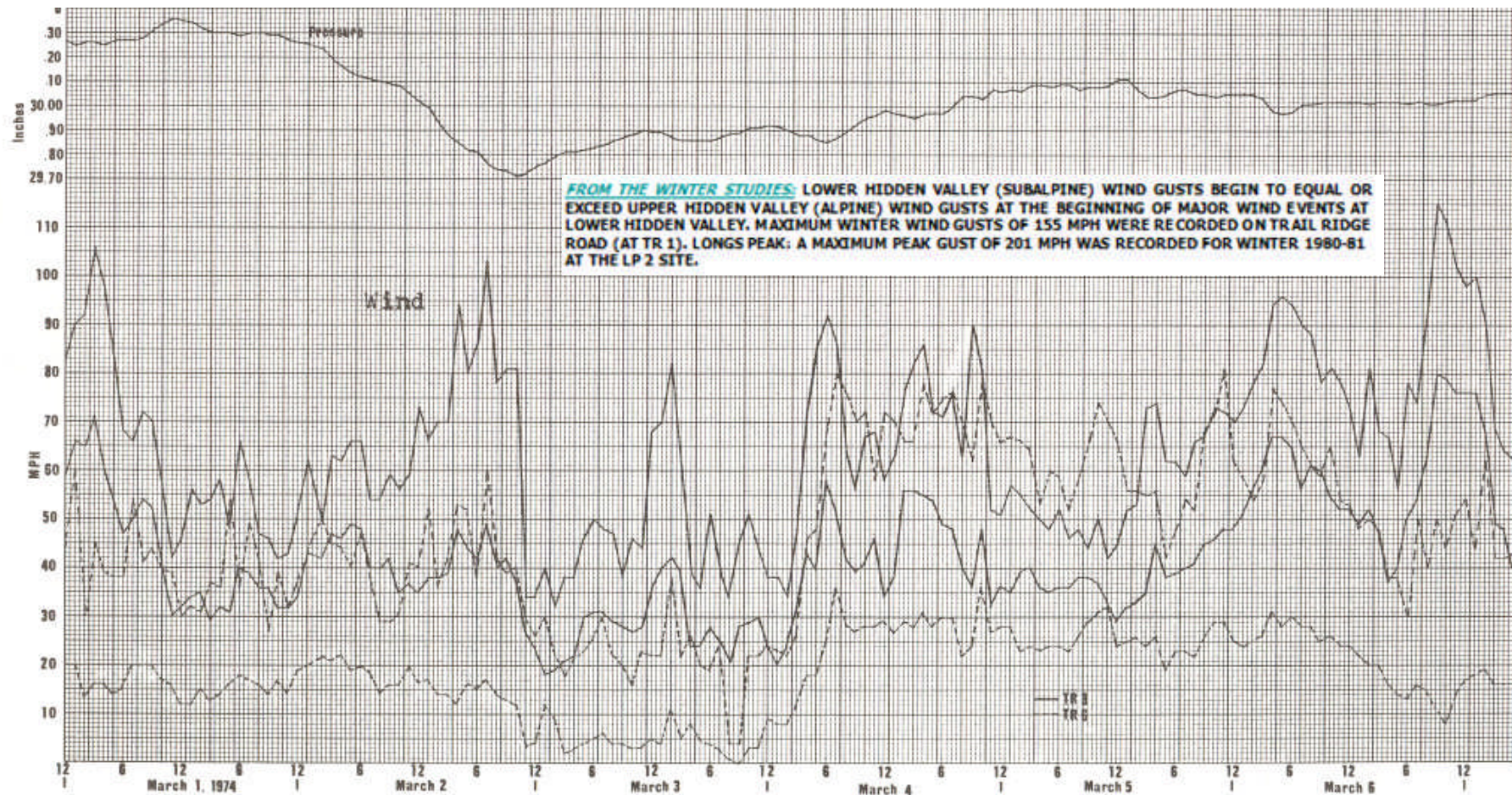
SCALE: 0-200 MPH:

After D. E. GLIDDEN

**ANEMOGRAPH FROM TR 1 SITE (ABOVE FOREST CANYON OVERLOOK) ON DECEMBER 12TH, 1973  
NOTE RANGE OF TURBULENCE AND HIGH GFs WITH NUMEROUS GUSTS > 140 MPH**



## THE COMPLICATED RELATIONSHIP OF SURFACE PRESSURE TRENDS TO WIND MAXIMA AND AVERAGES IN A ROCKY MOUNTAIN ALPINE AND SUBALPINE ENVIRONMENT



HOURLY PEAK GUSTS AND AVERAGE WIND SPEEDS DURING THE FIRST WEEK OF MARCH 1974 FOR UPPER (TR 3) AND LOWER (TR 6) HIDDEN VALLEY, ROCKY MOUNTAIN NATIONAL PARK. FOR WIND, THE SOLID LINES REPRESENT DATA AT TR 3 AND THE DASHED LINES AT TR 6. NOT ALL WIND MAXIMA WERE ASSOCIATED WITH SIGNIFICANT PRESSURE FALLS OR RISES. ON MARCH 2, NOTE THAT WIND MAXIMA OCCURRED JUST PRIOR TO PRESSURE MINIMA, SIMILAR TO THE MWO FEB. 3-4, 1974 MAXIMA OF 166 MPH. HOWEVER, ON MARCH 6<sup>TH</sup> THE RMNP WIND MAXIMA OF 115 MPH OCCURRED WITH LITTLE PRESSURE CHANGE.

TR 3 IS AT 3536 METERS; TR 6 IS AT 2913 METERS  
PRESSURE RECORDED AT TR 6

AFTER D. E. GLIDDEN,  
WINTER WIND STUDIES IN ROCKY MOUNTAIN  
NATIONAL PARK, 1982



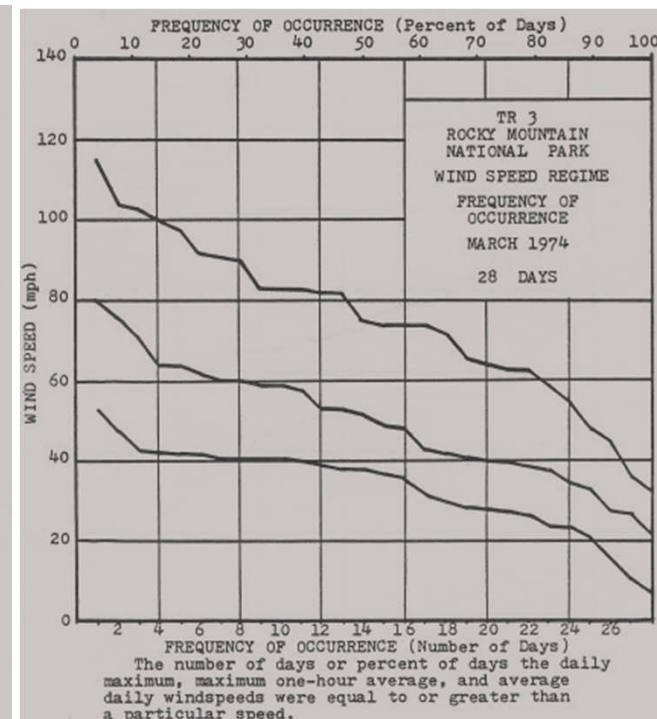
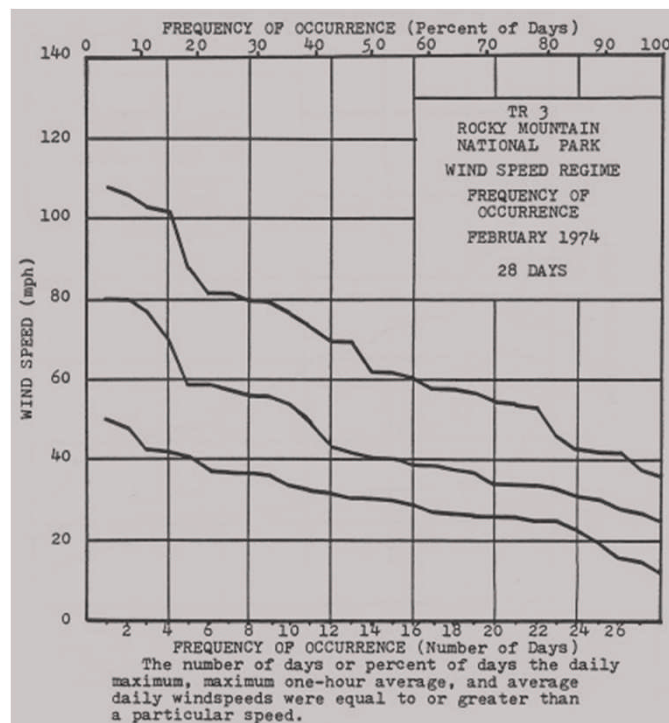
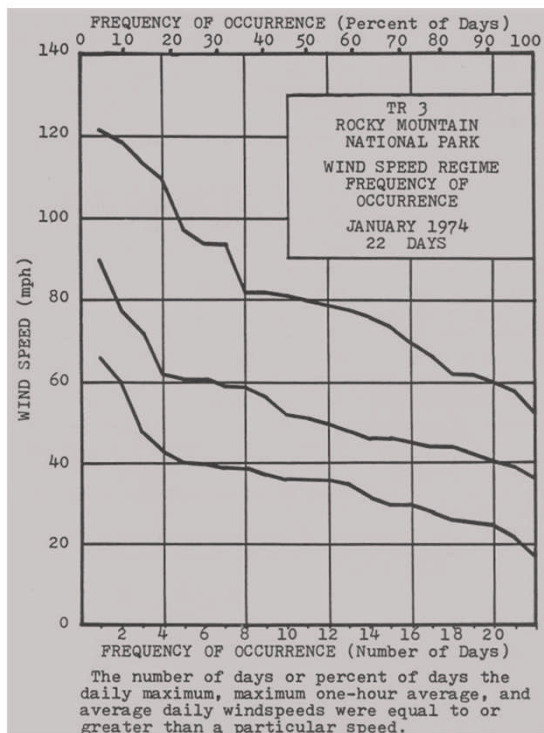


Table 13. Comparison of hourly and 5-minute GFs at AVC for June 1980.

	Hourly	5-minute	% Difference
Maximum	3.58	2.03	43
Mean	1.58	1.36	14
Minimum	1.00	1.03	03

Table 14. Comparison of 5-minute GFs, AVC (summer) and Mount Washington, New Hampshire (100 hours).

	AVC	Mount Washington
Maximum	2.03	1.35
Mean	1.36	1.17
Minimum	1.03	1.09
Sensor Height (m)	9	12

Table 15. Hourly averages of GFs and windspeeds at 6-hour intervals, AVC, summer 1980.

Hour Ending (LST)	0100		0700		1300		1900	
	GF	WS	GF	WS	GF	WS	GF	WS
Average Maxima	2.19	32.7	2.27	34.3	2.68	40.0	2.49	36.0
Mean	1.48	19.7	1.45	19.3	1.73	21.8	1.65	21.6
Average Minima	1.13	8.7	1.08	8.7	1.31	13.0	1.31	9.7

GF = Hourly Gust Factor  
WS = Hourly Average Windspeed (mph)



Table 9a. The frequency of occurrence of daily maximum one-hour average windspeeds  $\geq 64$  mph (29 m/s) at TR 3, October 1973-May 1974.

	O-N <sup>1</sup>	J	F	M	A	M	PERIOD
No. Days $\geq 64$ mph	2	3	4	5	2	2	18
% Days $\geq 64$ mph	8	12	14	18	8	7	11
Days With Data	24	24	28	28	25	28	157

1. Data from TR 1

Table 10. The frequency distribution of average hourly windspeeds at TR 1 and TR 3, RMNP, Winter 1973-74.

One-hour Average Windspeed	Total Hours of Occurrence	Total Hours of Occurrence	Frequency Distribution
MPH	Number	%	MPH %
0-9	355	8.74	$\geq 0$ 100.00
10-19	753	18.53	$\geq 10$ 91.26
20-29	1,027	25.28	$\geq 20$ 72.73
30-39	914	22.50	$\geq 30$ 47.45
40-49	620	15.26	$\geq 40$ 24.96
50-59	252	6.20	$\geq 50$ 9.70
60-69	108	2.66	$\geq 60$ 3.49
70-79	23	0.566	$\geq 70$ 0.837
80-89	10	0.246	$\geq 80$ 0.271
90-99	1	0.025	$\geq 90$ 0.025

Total Hours = 4,063

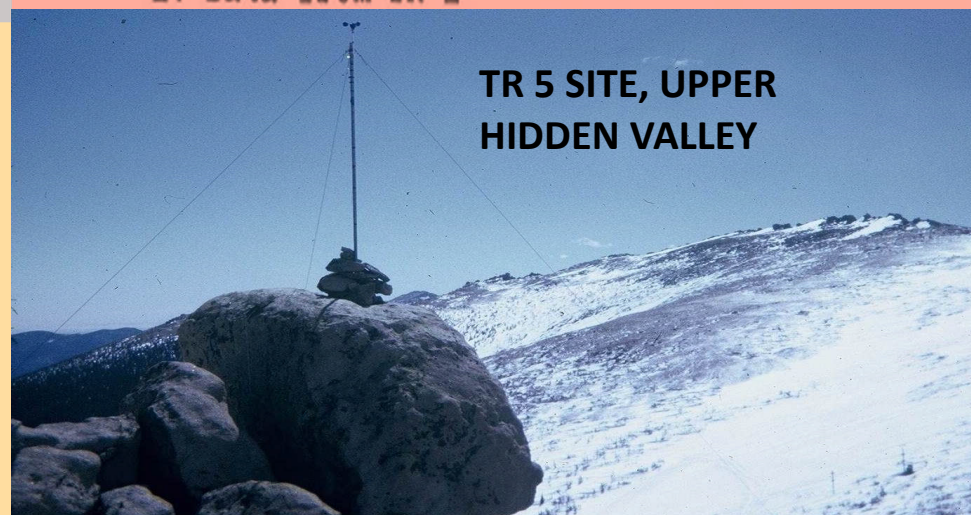
Total Possible Hours = 5,832

Percent of Hours With Data = 69.7%

Table 9b. The frequency of occurrence of daily average windspeeds  $\geq 32$  mph (14 m/s) at TR 3, October 1973-May 1974.

	O-N <sup>1</sup>	J	F	M	A	M	PERIOD
No. Days $\geq 32$ mph	12	13	12	16	2	9	64
% Days $\geq 32$ mph	50	59	43	57	8	32	41
Days With Data	24	22	28	28	25	28	155

1. Data from TR 1



TR 5 SITE, UPPER  
HIDDEN VALLEY

Table 5. The distribution of weekly wind maxima by high wind speed classes for TR 2 and TR 5, RMNP, Winter 1973-74.

Site	No. Weeks	% Weeks $\geq 74$ mph	% Weeks $\geq 90$ mph	% Weeks $\geq 110$ mph	Period Peak Gust
TR 2	30	80	57	17	139
TR 5	18	95	61	11	126



Table 4. The wind regime summary for TR 3 and TR 6, RMNP, January-May 1974. (MPH)

	J	F	M	A	M	PERIOD
Peak Gust						
TR 3	122	108	115	113	111	122
TR 6	64	77	81	88	65	88
Average Daily						
Maximum						
TR 3	80.4	67.4	76.3	57.0	63.5	68.9
TR 6	M	51.3	52.1	43.6	39.5	46.6
No. Peak Gusts						
≥74 mph						
TR 3	392	68	1,014	158	367	1,999
TR 6	M	1	20	4	0	25
No. Peak Gusts						
≥100 mph						
TR 3	322	35	79	67	22	525
TR 6	M	0	0	0	0	0
Maximum One-hour						
Average						
TR 3	90	80	80	87	72	90
TR 6	M	26	36	30	24	36
Maximum Daily						
Average						
TR 3	65.7	50.0	53.1	42.7	47.6	65.7
TR 6	M	M	13.6	11.1	9.8	13.6

Table 11. Comparison of gust factors for several heights above ground, elevations, and seasons, RMNP.

Site	AVC	TR 3	TR 6
Month/Year	Aug 80	Mar 74	Mar 74
Maximum GF	2.00	2.10	3.17
Mean GF	1.57	1.58	2.42
Minimum GF	1.17	1.32	1.73
Mean Monthly Windspeed (mph)	20.1	34.1	13.6
Monthly Peak Gust (mph)	79	115	81
Site Elevation (m)	3,596	3,536	2,914
Sensor Height Above Ground (m)	9	3.7	13



TR 2 WIND SENSOR,  
KNIFE EDGE, 1973-74

A gust of 155 mph (69.3 m/s) was recorded at TR 3 in December 1973. More recently, during winter storm research on Long's Peak Summit in 1980-81 (a period of subnormal regional airflow), two separate storm events produced maxima of 173 mph (77.3 m/s) and 172 mph (76.9 m/s) on the 4,345 m peak.

Data on gust ratios or gust factors (GFs) for the alpine are as rare as that for windspeed. GFs are determined from the ratio of the peak gust (PG) to the average windspeed for some specified period of time. For example, the hourly GF refers to the ratio of the peak gust/average hourly windspeed.

The response characteristics of the instruments (or the capacity of the sensors to respond quickly enough to represent a "true" approximation of the actual gust), and the damping effects which may be introduced by even small amounts of ice on the sensor, are important considerations in the field of anemography.

The mean hourly GF at AVC for summer was 1.58; the average and extreme maxima were 2.20 and 4.28, respectively. An hourly GF of 1.58, for example, indicates that an hourly average wind-speed of 20 mph (9 m/s) has a peak gust of 32 mph (14 m/s).

Maximum daily one-hour GFs  $\geq 2.0$  occurred on 17 days in June, 20 days in July, and 16 days in August.



Table 9. The hourly gust factor regime, and associated meteorological variables, for AVC, summer 1980.

	J	J	A	SUMMER
Extreme Maxima	3.58	4.28	3.53	4.28
Average Maxima	2.23	2.22	2.16	2.20
Mean	1.58	1.54	1.61	1.58
Average Minima	1.24	1.19	1.20	1.21
Extreme Minima	1.00	1.00	1.00	1.00
Mean Temperature (Fahrenheit)	45.8	50.9	49.6	48.8
Mean Relative Humidity (%)	39.5	57.8	56.8	51.4
Mean Pressure (Millibars)	1021.0	1022.7	1019.3	1021.0

Table 10. Comparison of extreme gust factors for different alpine sites in RMNP, summer versus winter.

	<u>1980</u>			<u>1973</u>
	<u>June 21</u>	<u>July 25</u>	<u>August 9</u>	<u>December 12</u>
Maximum Hourly GF	3.58	4.28	3.53	4.23
Hour Ending (LST)	0400	1700	1400	0500
Mean Hourly GF	1.66	1.64	1.76	2.26
Hourly Peak Gust (mph)	43	60	53	144
Hourly Average				
Windspeed (mph)	12	14	15	34
Average for Day (mph)	17.5	17.2	16.3	44.2

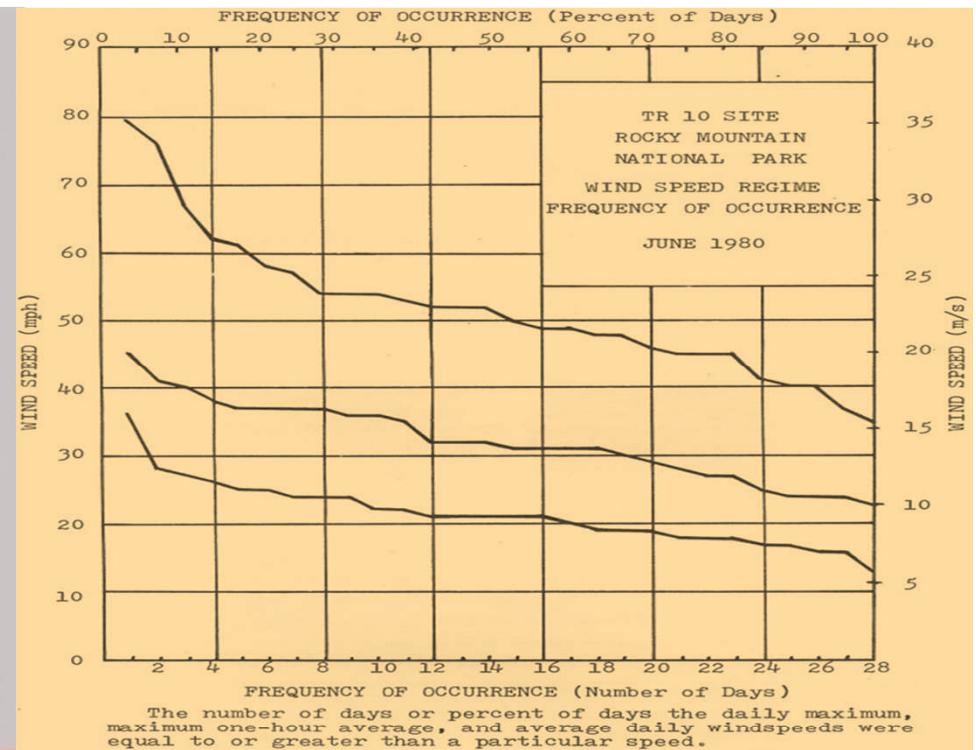


Table 12. AVC GFs for average 5-minute windspeeds  $\approx 30$  mph (13 m/s), June 1980.

Maximum	2.03
Mean	1.36
Minimum	1.03
n, sample	1,371